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# Surgical Robots: Current Performances and Perspectives of Development and Use

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***Abstract:*** *The surgical field represents a delicate and complex side of medicine and the introduction of robots has considerably improved the lives of patients and doctors. Robotic surgery has advanced astonishingly in recent decades and specialists are trying to exceed the expectations that people may have from the robots used in medicine at the present time. The technology used in these robots continues to amaze not only by the complex way in which they work, but also by the fact that soon the operations will be able to be fully automated or carried out even remotely. This paper broadly presents an evolution of robotic surgery from the first application of robots in the surgical field to the present.*

***Keywords:*** *Robot, surgeon, robotic surgery, da Vinci Xi, Mako*

## 1. Introduction

Once the robots have been implemented in the surgical field, the quality of the medical act has increased considerably and this is largely due to the way of how the robots are working because they have a much higher accuracy compared to the surgeon's hand.
The robots improve the dexterity and abilities of the doctor and they offer a better visibility during interventions because they use advanced imaging systems.
Even though they have demonstrated impressive performances, a surgical robot is different from an industrial one because it does not have the same autonomy and requires assistance from doctors during surgery.
The present work aims to highlight the complexity and performances of these medical robots, while demonstrating how much robotic surgery has advanced in recent years and where it is headed. The research methodology and development of this scientific paper is based on recent experiments and specialist's demonstrations, brochures and professional journals, case studies and computer-aided design.

## 2. Present state

### 2.1 General considerations

The first application of a robot in medicine was made in the field of neurosurgery when an industrial robot, PUMA 200, was successfully used for a brain biopsy procedure in 1985.


**Fig. 1.** PUMA 200, the first robot used to assist human neurosurgery [2]

PUMA 200 (Programmable Universal Machine for Assembly) was, in fact, an industrial robotic arm originally created for the General Motors company. Under CT guidance, PUMA performed a brain biopsy on a 52-year-old man with a deep brain injury. This robot was able to precisely position the biopsy needle and it is considered the prototype of the robotic systems which are now used in neurosurgery [1].
Medical interventions assisted by robots represent a completely different experience from classic surgery therefore, doctors do not get to operate with them immediately and they have to go through certain stages before. The first step would be to practice in virtual programmes. In this regard, simulators for robotic surgery exist. They even have a haptic feature that helps surgeons feel the resistance of the tissues they need to sew or dissect, thus surgeons experience an environment as close as possible to reality. The next step is to operate on animals and then pass an exam that brings them accreditation in robotic surgery [1].

### 2.2. Surgical robots used in Romania and worldwide

There are surgical robots in 15 public and private hospitals, and only 8 robots are functional, the others not being used, mainly because of financial reasons. *Regina Maria* is the health network in Romania that has 4 surgical robots and two of them are da Vinci Xi robots - the best performing surgical system currently available [3].
The da Vinci Xi robot is an ultra-performance system, controlled by the doctor from a computerized console, through which the surgeon simultaneously manipulates the 4 robotic arms. An arm is designed to accurately handle the 3D and HD endoscope, and the other 3 arms handle the surgical instruments. The robotic arms are articulated, they have 7 degrees of freedom and perform a natural movement, but much more extensive and accurate compared to the one made by the human hand. The movements of the surgeon's hands are filtered and transformed by the system to become much more precise, without tremors. The 3D image transmitted by the robot can be magnified up to 10 times, observing even the smallest details [4].
An overview of the da Vinci Xi performing system is represented in Fig. 2, and the Fig. 3 and 4 closely show the arms of the robot and the console where the surgeon sits and through which he handles the robot. The console has two joysticks which the doctor uses for transmitting movements at the robot.

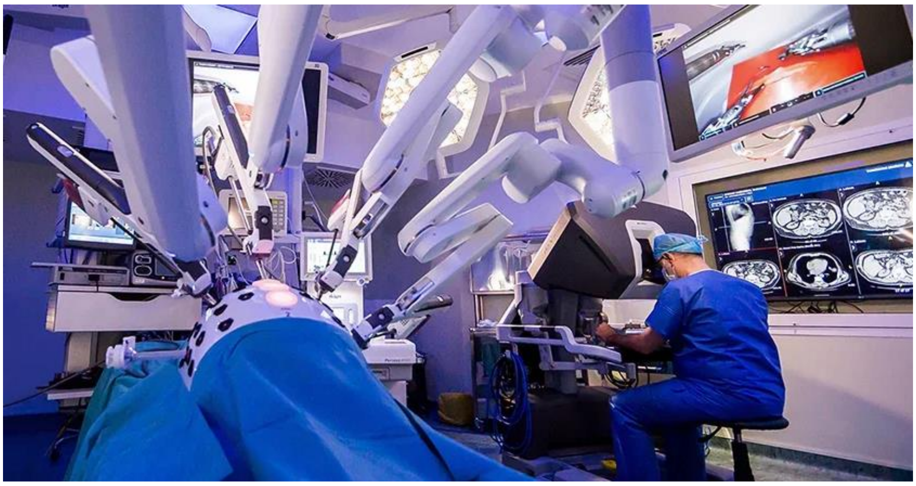

**Fig. 2.** The da Vinci Xi robot [4]

With the help of the da Vinci Xi robot, the surgeon manages to enter narrow anatomical spaces, thus operating millimetrically, with great accuracy. In the operating field, da Vinci Xi far exceeds the doctor also because of its superior vision, he rendering high-quality images from hard to reach areas [4].

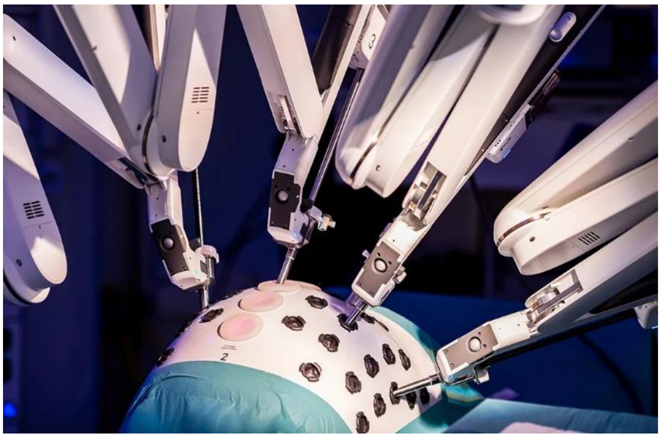

**Fig. 3.** The arms of the da Vinci Xi robot [3]


**Fig. 4.** The console through which the surgeon controls the da Vinci Xi robot [3]

The second surgical robot introduced in Romania is Mako, considered the first robot in Eastern Europe used in orthopedic hip and knee replacement surgery. Mako is rather a robotic arm that provides an excellent precision to the surgeon's hand. The robot is intended for total hip arthroplasty and total and partial knee arthroplasty. From all of the prosthesis procedures, the knee one is the most difficult to achieve because it involves an extremely complex articulation which requires high precision. The Mako robot manages to provide this precision, making the difference between the classic operation and the one where robots are integrated [3].

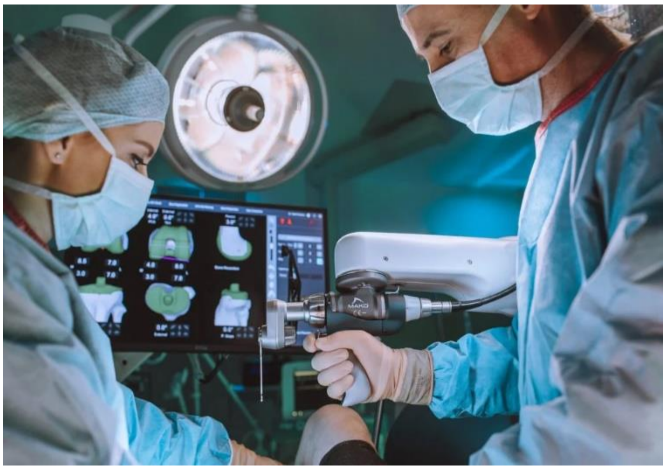

**Fig. 5.** The Mako robot handled by the surgeon [3]


**Fig. 6.** The Mako System [5]

Before any intervention, the problem is assessed and a customized 3D model of the prosthesis is designed according to the anatomy of each patient [3].
Also, Mako uses haptic technology ensuring that only the affected bone is sectioned. The robotic arm will emit a warning sound if the surgeon exceeds the limits created in the operative plan [5].
Following the use of the Mako robot in interventions, many things have been observed: reductions in pain and recovery time for the patient, reduced use of pain medication and reduced postoperative complications. Fig. 7 contains a graph which indicates the pain experienced by patients over a period of 90 postoperative days, both for the classic operation, performed only by the surgeon, and for the operation in which the Mako robot was involved. Throughout these 90 postoperative days, patients felt less pain in the case of interventions performed with the Mako robot [5].

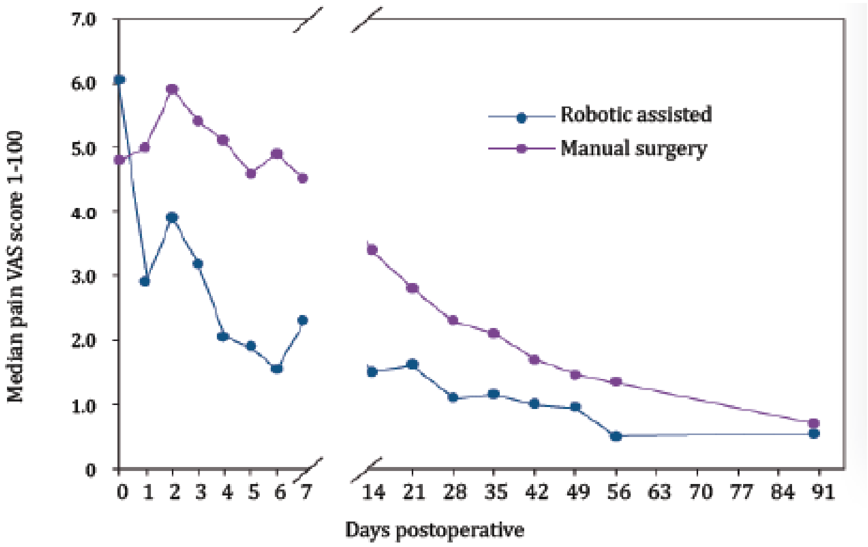


**Fig. 7.** Visual analog scale for 90 days after surgery [5]

According to the study conducted by Raed A. Azhara, Mohamed A. Elkoushyb and Saad Aldousarica in 2019 (article: Robot-assisted urological surgery in the Middle East: Where are we and how far can we go?), it turns out that the Middle East possesses only 1% of robotic systems da Vinci surgical systems installed worldwide (of which approximately 19 in Saudi Arabia; 6 in Qatar; 2 each in Kuwait and Lebanon; 3 in the United Arab Emirates; and only one in Egypt), while in Europe and the USA the presence of robots surgical da Vinci is much more significant, as follows: France 90 pcs., Italy 84 pcs., Germany 77 pcs., Belgium 34 pcs., Turkey 34 pcs., and 2344 pcs. installed in the USA.

### 2.3. Robotic automation in surgery

Robotic automation in surgical field has highly developed and it is demonstrated by current researches. A team of experts from Johns Hopkins University designed "STAR" (Smart Tissue Autonomous Robot) which was able to perform laparoscopic surgery on the soft tissue of a pig without being guided by the human hand [6].

Experts have equipped the robot with a three-dimensional endoscope and advanced imaging systems that provide more accurate views of the operating field. Because of its unpredictability, soft tissue surgery is particularly difficult for robots as they are forced to adapt quickly to deal with any unexpected obstacles in case of necessity. STAR has in its composition a new control system which can adjust the surgical plan in real time, like a surgeon would. Therefore, the robot has 3 essential functions: planning, adaptability and execution. Experiments showed that the robot produced significantly better results than doctors performing the same procedure individually. STAR is an improved version of a robot from 2016 which precisely operated on the intestines of a pig. The old version made a larger incision to access the intestine and has required more guidance from the doctors. The actual study represents a significant step in robotics for fully automated surgery on humans [6].

The robot uses artificial intelligence along with haptic and virtual sensors during surgical interventions and has been shown to outperform surgeons in certain tasks based on quantitative analysis [7].

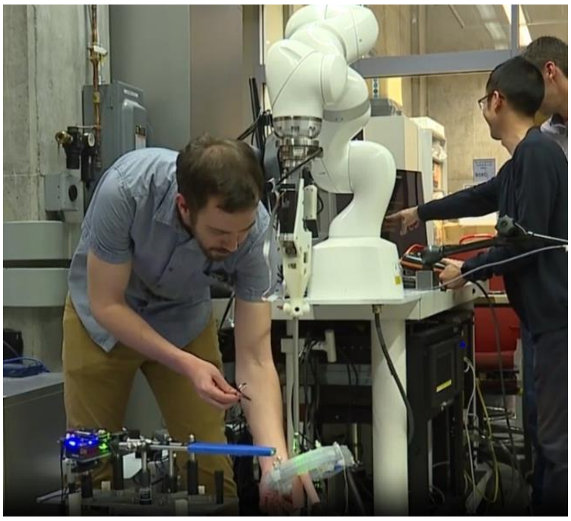

**Fig. 8.** The autonomous robot STAR [8]

STAR gives the surgeon a supervisor role who monitors the operation process and interferes only if it's necessary. Experts said that the robot can work for a long time ensuring the same accuracy. The team expects that in about 5 years, STAR will be in the operating rooms [8].

### 2.4. Remote robotic surgery

Robot-assisted surgery has advanced so far that a question of operating remotely with the help of robots arises. The most recent study in this regard was done by the Monogram Orthopedics company which is revolutionizing knee arthroplasty and orthopedic implants. Monogram demonstrated the possibility of remote operation in a recent experiment from March 2023 where it was demonstrated that it is possible to operate from a distance of approximately 1743 miles. From New York, with the help of a pedal, the surgeon guided the robot which was located in Austin, Texas. The main steps of the procedure were: detection of the femur and tibia, points control recording, actual cutting with the robot, and finally checking the articulation [9].

**Fig. 9.** The monogram robot in the operating room (at Austin) [9]

**Fig. 10.** The pedal used by the surgeon from New York to control the robot's positions [9]

The robot proves to be effective due to several characteristics such as: 7 degrees of freedom which allow a wide range of movement, closed loop control system and an actively navigated milling which is easily and accurately carried out in the idea of preparing the space for the implant. The tool used is a sagittal saw or a milling cutter. The surgeon uses the high-performance imaging system provided by the robotic system. The CT scan (Fig. 11) represents the patient's plan which is the basis of the operation. With the help of this plan, the doctor can access what he wants for analysis and surgical intervention. First, the doctor analyzes this plan, then the position is checked, the femur is examined first, then the tibia, and the control points for each one are recorded. These steps are followed by the actual cutting procedure exemplified in Fig. 12 [9].

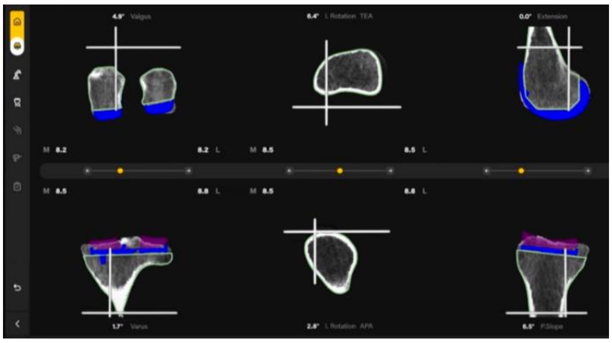

**Fig. 11.** The patient's CT plan [9]


**Fig. 12.** Incision [9]

The implants used by Monogram company also involves a different technology. Currently, cemented implants are used in over 90% of joint replacement surgeries. These can break, causing problems over the time. Monogram says it will use porous metal press-fit protheses, which allow the bone to fuse with the metal and hold it in place as naturally as possible [10].

### 3. Case study – Finite element analysis of a telemanipulator

The case study concerns the finite element analysis of a telemanipulator used in minimally invasive surgery to demonstrate its performance. Fig. 13 shows the 3D model of the telemanipulator made in the SolidWorks program [11].

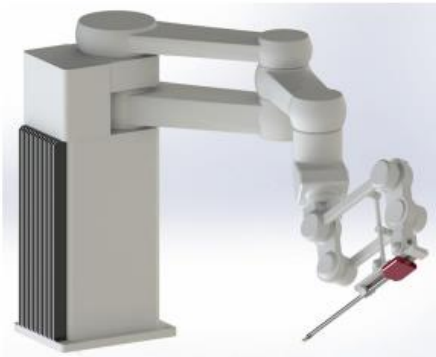

**Fig. 13**. The 3D model of the telemanipulator [11]

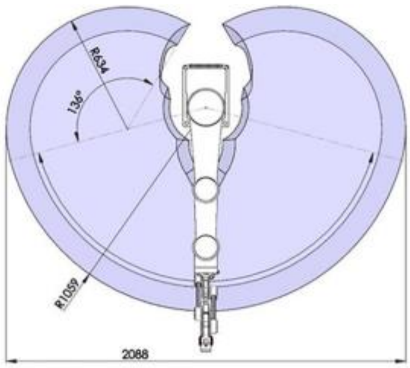


**Fig. 14.** The telemanipulator's workspace [11]

For the finite element analysis, two cases are represented in Fig. 15. In the first case (a) a force of 50 N was applied, and for the second case (b) one of 5 N. Images show the X-axis displacement results for the positive direction in case (a) and the negative direction in case (b).

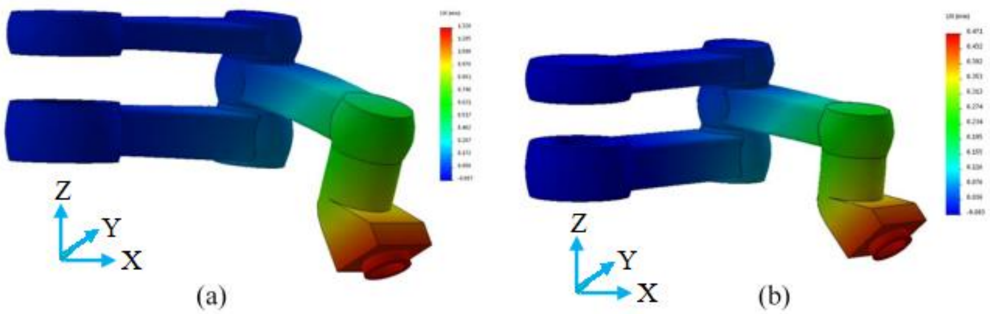


**Fig. 15.** Finite element analysis (after [11])

The results obtained from the finite element analysis (FEA) show that the resulting maximum displacements do not exceed 1.5 mm in all of the considered cases [11].

Thus, the resulted displacements from this analysis are very small and do not affect the performance of the robotic arm during operation.

## 4. Conclusions

The introduction of robots in surgical interventions offers numerous advantages such as: greater precision during the medical act, smaller incisions, therefore smaller scars, reducing the risk of infections, quick recovery, reduced length of hospital stay.
Also, with the integrability of robots in interventions, less blood was lost during surgery, so it is a less need for blood transfusions, less pain and less administration of analgesics.
Operating with robots is a completely different experience and doctors go through a training process in order to be able to operate with them. Same as patients, the doctors have seen improvements, reporting less fatigue following robot-assisted interventions and feeling a greater satisfaction for the medical procedure.
Currently, a robot used in the operating room does not have the autonomy of an industrial robot. More specifically, it does not perform an operation after receiving an order, and that is precisely why the surgical robots currently used in operations are assisted and guided by doctors. However, recent studies have shown that robotic automation in surgeries is possible, a concrete case being the STAR robot from Johns Hopkins University.
Although, at the present moment, robots assist doctors during interventions, in the future seems that they will perform the operations by themselves, and the surgeon will only supervise the process. Current studies demonstrate this possibility and reveal how powerful the technology used for medical robots is.

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